A Study of the Root Rot-Nematode Complex and the Comparative Yield of 17 Varieties of Alfalfa in Washington County, Utah

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A STUDY OF THE ROOT ROT-NEMATODE COMPLEX AND THE COMPARATIVE YIELD OF 17 VARIETIES OF ALFALFA IN WASHINGTON COUNTY, UTAH

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INTRODUCTION

Alfalfa is the major forage crop in the state of Utah. It is especially important in Washington County where mild temperatures allow the production of 4 to 5 cuttings each year, and where the dairy industry is increasing.

During the past few years a root rot and insect complex has raised havoc with the longevity of stands of recommended varieties in this part of the state. Alfalfa fields have become so unprofitable that many are plowed up after 2 to 3 years of production. Since the establishment of alfalfa is expensive, it is imperative that the farmer retains a good stand over several years. This fact, along with the great demand for alfalfa hay, warrants a study to determine the causal agents, and to select a remedy for this problem.

The objectives of this investigation are to determine if alfalfa stem nematodes are present in the area, to determine the major root rot diseases, and to select varieties which are best adapted to the area for maintaining longevity of stand and high yield per acre.

REVIEW OF LITERATURE

Disease complex

The decline of alfalfa stands due to a complex of diseases is a common problem of growers and plant breeders in recent years. Keener (1948) stated that decline of stands in Arizona was due to a root rot complex of *Corynebacterium insidiosum*, *Fusarium* spp., *Rhizoctonia solani*, and *Phymatotrichum omnivorum*.

Dean (1948) reported that *Fusarium oxysporum* var. *medicaginis*, *Colletotrichum trifolii* and a few other unidentified fungi were responsible for great losses in stand at Columbus, Ohio, during the years 1946 to 1947. Crown rot of alfalfa in California is a complex from which *Phytophthora cryptogea*, *Stagnospora meliloti*, *Fusarium* spp., *Coniothyrum* spp., and *Pythium* spp. have been isolated (Erwin 1955).

During a 2 year study in Alberta, Canada, Hawn and Cormack (1952) isolated 5 *Fusarium* spp., *Rhizoctonia* spp., and a low temperature basidiomycete as the cause of a disease complex. McDonald (1955) reported similar isolation from a root rot complex in Manitoba.

Steiner (1954) stated that soil borne plant diseases are complex and that nematodes are quite frequently members of such groups acting as initiators, cooperators, synergists, or aggravators.

Smith (1948-1949) reported that bacterial wilt has been found wherever the stem nematode is present in Nevada. According to Weimer and Sell (1948), Fusarium wilt and nematodes are prevalent together on alfalfa in Georgia. In Arkansas a serious complex of nematodes and *Fusàrium oxysporum vasifectum* attacks alfalfa plants, and reduces stands (Walters and Slack 1956).

Phymatotrichum root rot

Phymatotrichum root rot, commonly called cotton root rot, was known to attack alfalfa in this country as early as 1869 and was first extensively studied by Pammel in 1888. He decided the fungus was *Ozonium auricomum* Lk. (Pammel 1888). Shear determined that it was a new species and named it *Ozonium omnivorum* (Shear 1925). When the conidial stage was found the scientific name of the organism was changed to *Phymatotrichum omnivorum* (Shear) Dug. (streets 1937).

The disease is widely distributed in the semi-arid southwestern United States and in the northern part of the Republic of Mexico (Streets 1937). Richards (1933) first recognized this disease in Washington County, Utah, near the townships of Ivins, Santa Clara, St. George, and Hurricane. Richards (1933) and King, *et al*. (1932) found the fungus to be of an indigenous nature in virgin land in Utah and Arizona.

The first symptom is a slight yellowing or bronzing of the leaves. Soon after a slight wilting is observed and the entire plant becomes straw colored. A typical infected field area is roughly circular. These circular spots consist of an outer ring of recently dead plants, an inner ring where only the bleached stubble of dead plants remain, and a central zone occupied by re-established plants. Strands of mycelium can be found on the most recently wilted plants, and examination shows that the roots are already extensively decayed (Streets 1937).

Ratliffe mapped root rot spots for 17 years at the San Antonio Experiment Station and discovered that the spots behave independently (Streets 1937).

McNamara, *et al*. (1931) reported the behavior of the individual spots has no relation to the nature of the soil, or the crop being grown, but is due to the action of the fungus itself or to some unknown environmental condition.

Taubenhaus and Ezekiel (1936) reported that 2116 species belonging to 131 families were tested in Texas for susceptibility to this fungus. Four hundred and eight were immune, 403 resistant, and 1305 were moderately to extremely susceptible. All monocotyledons tested were immune to the disease. Water soluble labile substances, minute quantities of acidicester soluble substances, and alkaloids present in the roots of the monocotyledons have been suggested as the basis for immunity by Moore (1933), Ezekiel and Fudge (1938), and Greathouse and Rigler (1940).

Infection occurs within a pH range of 4.1 to 8.9, with a pH of 7.0 being the optimum. The organism is most prevalent in heavy soils and is found only in rare instances in sandy soils or those of low fertility (Streets 1937).

Taubenhaus and Dana (1928) concluded that high temperature was favorable to the organism, humidity had no direct influence, and rainfall was extremely important to the incidence of disease. A study by Rogers (1939) indicated that 25 percent moisture on an oven dry basis was optimum for growth. The optimum temperature was 27° C.

King, et al. (1934) stated that organic materials applied to the soil in the form of manure delayed the incidence of the disease because the abundance of microorganisms created an unfavorable soil condition for growth of the fungus.

There is some disagreement in the literature concerning the effects of commercial fertilizers on the organism. Jordon, et al. (1929) report that the incidence of root rot was reduced on Wilson very fine sandy loam by nitrogenous fertilizers and increased by those containing phosphorus. The effects on heavier soils were less pronounced. Reynolds and Rea (1934) reported that there was no relative effects from fertilizers on the root rot in 85 experiments from 1930-1932. Streets (1937) stated that nitrate nitrogen increased growth of the fungus and phosphates increased the number of surviving plants.

Bayles (1932) reported that more than 50 varieties and strains of alfalfa were tested for resistance at the Experiment Station at Balmorkea, Texas over several years but none were found to be resistant. He found that varieties which have a strong central tap root are less likely to succeed in regrowth after infection than those which branch more freely.

Fusarium wilt

Several species of Fusarium have been recorded as causing root rots of alfalfa. Cormack (1937) reported that 20 distinct species or varieties of Fusarium have been found on this crop. In Canada *Fusarium arthosporioides*, *F. culmorum*, *F. poae*, *F. avenaceum*, and *F. scirpi* var. *acuminatum* cause serious root rots. In Arkansas and South Carolina *F. vasifectum* seriously infects alfalfa plants. *F. oxysporum* var. *medicaginis* is found in California and Mississippi and *F. soloni* has been reported causing a serious disease in Arizona. *F. roseum* also is found in some areas of the United States causing alfalfa root rot.

Cottam (1921) reported that a Fusarium species was the cause of a dry rot of alfalfa in southern Utah and possibly Arizona in 1920. He gives a brief description of the symptoms but lists no particular species as the causal agent.

Fusarium oxysporum var. *medicaginis* is probably the most important species in United States which attacks alfalfa. H. L. Westover observed the first attacks on alfalfa by this species on plots on the

Government Experiment Station at West Point, Mississippi, in September 1926 (Weimer 1927).

At first symptoms seemed to resemble bacterial wilt, but were not quite typical. Usually the disease becomes evident in one stem, which may be dead before signs of infection appear elsewhere. Leaves turn bright yellow, and tips of stems may wilt during the hot part of the day, especially when the soil becomes dry. An examination of the root shows a striking cinnamon brown or reddish brown discoloration of the vascular system (Weimer 1928). Cormack (1937) found that F. culmorum often causes symptoms similar to those described by Weimer for the oxysporum species.

Staten and Leyendecker (1949) definitely proved the pathogenicity of F. solani. The reddish brown vascular discoloration originated in most cases from lateral roots. Many infections with this pathogen remained localized in the crown and caused a typical crown rot.

The Fusarium fungi usually enter the alfalfa roots through injuries. They spread from one plant or one area to another by irrigation and drainage water, machinery, man, and livestock (Weimer 1927) and (Staten and Leyendecker 1949).

New Mexico's 60th Annual Report (Anonymous 1948-1949) stated that high temperature, high soil moisture, and high humidity favor the development and spread of F. solani. The optimum temperature for F. oxysporum var. medicaginis was 25° C. with the best soil moisture at 55 percent of water holding capacity (Weimer 1930). The best temperature for growth of the 5 species in Canada was 24° C. The optimum pH range was 4.0 to 9.5 with the best growth occurring in alkaline soils (Cormack 1937).

Westover's fertilizer plot studies indicated that neither lime or superphosphate had an appreciable effect on the prevalence of the disease (Weimer 1928). Cralley (1953) stated that generally the disease was aggravated by high nitrogen and phosphorus, and low potassium levels.

In Westover's trials no strains were found highly resistant to Fusarium (Streets 1937). Orestan and Nemestan had the most depleted stands of 14 varieties tested for resistance in South Carolina (Armstrong and Armstrong 1954). Cralley (1953) reports that none of their principle varieties, including Buffalo, were resistant. In Canada, a Falcata alfalfa possessed resistance to F. avenaceum (Cormack 1942). Hansen and Allison (1951) indicated that there were no strains of high resistance in a North Carolina test.

Reports from New Mexico indicated that strains NM5-88-0 and NM6-268-0 have given higher yields than New Mexico Common due to resistance to bacterial and fusarium wilts (Anonymous 1948-1949) and (Anonymous 1949-1950).

Bacterial wilt

"Bacterial wilt is the most serious alfalfa disease on the American continent," (White 1949). The disease is widespread but it does not occur in areas of 25 inches of rainfall per year or less, unless irrigation is practiced (Jones 1940).

It was first reported by Jones and McCulloch (1926) who found the bacterium, Corynebacterium indidiosum to be the causal agent.

The disease is most prevalent during the first cutting and usually appears during the second or third year of production (Jones 1928). Plants become a pale yellow color and are dwarfed. Leaves are smaller and lighter green in color and often curl upward at the margins.

Wilting may occur on hot days. A discolored yellow to brownish wood is found in the roots beneath the bark in the vascular layer. This discoloration is caused by a bacterial exudate which plugs the conducting tissues and eventually results in death of the plant.

The bacteria are unable to enter an uninjured plant according to Peltier (1934). Jones (1928) reported that winter injury is correlated with bacterial infection. Nematodes are also a big factor in injuring roots and making entrance for the bacteria (Smith 1948-1949).

Jones and McCulloch (1926) stated that the pH range for best growth was 5.6 to 8.4 and that the optimum temperature range was between 1° C. and 31° C.

Several varieties have been developed with resistance to this wilt. Most of the resistance is from Turkistan sources. Peltier and Tysdal (1931) tested 62 imported lines of French and Turkish origin and reported Hardistan, Province, and Turkistan varieties had resistance. It appears resistance can be bred into any cross with careful selection (Jones 1949).

<u>Rhizoctonia</u>

Rhizoctonia was first found on alfalfa roots in Nebraska in 1890 by Webber and called <u>Rhizoctonia medicaginis</u>. From literature it is evident that <u>R. solani</u>, (Kuhn) and <u>R. crocorum</u> (Pers.) C. C. are the 2 most important species affecting alfalfa (Peltier 1916).

McDonald (1955) reported <u>R. solani</u> as a factor in the recent crown and root rots in Canada. The same species is a factor in crown bud necrosis in California (Erwin 1954a). Smith (1943) reported that the organism caused a quite serious canker of alfalfa in Nevada and California.

The disease is characterized by dark sunken areas, which sometimes have a brownish border. The diseased areas are usually circular, but in some instances may extend part way around the root. They are usually found where young roots emerge from the tap root and often a root stub can be seen in the center of the lesion. The lesions extend into the central region of the root, but there is very little spread up or down from the infected area. In some extreme cases the plants die within a year from seeding (Smith 1943).

Lesions develop abundantly at soil temperatures of 25° to 30° C., but not at temperatures below 20° C.

In a Nevada study isolates from other plant species produced no lesions on California Common variety of alfalfa except R-216 which was only weakly pathogenic. Isolate 102 which causes serious root lesions on alfalfa was pathogenic on roots of vetch, guar, and a few clovers. It was also pathogenic on stems of the Canada field pea (Smith 1945).

There is no mention of resistant varieties or strains of alfalfa in the literature.

Stagnospora

Jones and Weimer (1938) reported that *Stagnospora meliloti* Sacc., previously known only as a leaf spotting fungus, was found causing an undescribed root rot of alfalfa in California and Wisconsin.

The most distinguishing symptom of the disease is the reddish flecking of the bark and wood of an infected crown which occurs primarily in the winter. There is no stunting of growth associated with the disease. The root bark cracks and becomes rough and eventually the tissue becomes necrotic and rotten.

The fungus appears to be a wound parasite (Jones and Weimer 1938). Indications are found that this organism enters the plant through the above ground crown branches and progresses downward into the woody tissues and bark of the tap root. The disease develops at the margins of rays and does not approach or enter the vessels like bacterial wilt (Erwin 1955).

Erwin (1954) stated that the organism is difficult to isolate and grows very slowly in culture. He found that growth of mycelium was most abundant at 19° C.

Observations at Madison, Wisconsin, in 1940 showed evidence of varietal resistance or varying susceptibility to *Stagnospora meliloti* (Jones, *et al*. 1941).

Miscellaneous root rot diseases

Several other root rot diseases are found on alfalfa in limited areas. A diplodia crown rot of alfalfa caused by *Diplodia nutalensis* is found in Arizona (Sleeth 1951).

Nobel and Dawson (1953) reported a root rot caused by *Verticillium albo-atrum* in Scotland and Great Britain. Cormack (1946) stated that a sclerotina root rot caused by *Sclerotinia sclerotiorum* exists in Canada.

Phytophthora cryptogea causes a root rot of alfalfa in California (Erwin 1954). In Canada a root rot of alfalfa, clovers, and grasses was caused by an unknown basidiomycete (Cormack 1948). Perganino root rot is found in Argentina (Anonymous 1950).

Stem nematode

Edwards (1932) reviewed the literature on the stem nematode, *Ditylenchus dipsaci* (Kuhn). Its first occurrence on alfalfa was recorded by Kuhn in 1881. In 1922 it was found in Oregon on alfalfa and by 1929 it had spread to 26 states of the United States.

According to Thorne (1932) the nemas can destroy one-half to three-fourths of the alfalfa crop. Heaviest losses occur in fields which have been allowed to remain growing for over 5 years or those which have been replanted immediately following an old stand. The injury is most prominent at the time of the first cutting during the cool moist spring months, and the damaged area increases in the direction of water flow. The nemas over-winter around the crowns of plants and then attack the young shoots in the early spring at the joint of the growing point of the sheath or at the leaf axis, causing the buds to become clublike, thickened, and deformed. The stems swell and can be broken from the base rather easily.

This nematode has a host range of over 300 species. There are also biological races within the species, some infesting only one host and others many. Experimental results of a Nevada test indicated there are at least 2 races attacking alfalfa (Smith 1951). Some of the biological races which attack alfalfa can also infest _Trifolium repens_ and _Melilotus alba_ (Smith and Allen 1943).

It is a common theory that the nematodes damage the tissues and prepare the way for infections by bacteria and fungus pathogens. Smith (1948-1949) demonstrated this relationship with bacterial wilt.

Thorne (1932) learned that the nematodes can survive freezing temperatures to 19° C. for as long as three-fourths of an hour providing they are permitted to recover slowly. He also stated that they tend to be inactive during dry weather.

A resistant variety was developed in Argentina and named F. A. V. San Martin (Tome 1952). Nemestan is a resistant variety which was obtained as an introduction from Turkistan. From this variety 5 clones were selected, and synthetically combined into a variety called Lahontan (Smith 1955). A personal interview with Dr. Smith revealed that Lahontan was almost immune to the stem nematode, but was one of the most susceptible varieties to root knot nematode (<u>Meloidgyne</u> spp.). Brown and Goodey (1956) reported that Nemestan and Lahontan were resistant to nematodes in Great Britain when all others were susceptible. Nemestan was severely injured in a Virginia study (Fenne, <u>et</u> <u>al</u>. 1949). Lahontan and accessions derived therefrom exhibited only moderate resistance to North Carolina nematode collections (Allison 1956). Lahontan and Nemestan have given excellent resistance in Nevada tests (Smith 1948) and (Smith 1955). The variety Talent, which was developed in Oregon, also shows resistance to the stem nematode (Schoth, <u>et</u> <u>al</u>. 1952).

PLANT MATERIALS

Seventeen varieties of alfalfa (*Medicago* spp.) of economic or potential economic importance were included in this experiment. They were selected on the basis of their adaptation to the environmental conditions of the area, and disease and nematode resistance. A few varieties of unknown disease reaction were also included. Seed lots used are indicated by the F. C. number following the variety name.

Arizona Chilean (F. C. 24821) is a selection from an imported Chilean variety. It is a non-hardy variety adapted only to warm climates. It is questionable if this variety has any resistance to disease. In adapted areas it will outyield northern varieties.

Atlantic (F. C. 24044) was developed by the New Jersey Agricultural Experiment Station. It is presently adapted to areas in eastern United States were bacterial wilt (*Corynebacterium insidiosum*) is not a serious factor and where short rotations are used. It is a variegated variety, nonresistant, but more tolerant to bacterial wilt than Grimm.

Buffalo, (F. C. 24864) a selection of Kansas Common, was released by the Kansas Agricultural Experiment Station in 1942. It is adapted to the central and southeastern areas of the United States. It is also one of the recommended varieties for the state of Utah. This variety has a purple flower, upright growth, and medium sized stems. It is resistant to bacterial wilt and yields well in adapted areas.

B. Y. Strain is an alfalfa propagated by Andrew A. Borgeson of Santaquin, Utah, from seed harvested from vacant lots in Salt Lake City.

It is purported to be from alfalfa which Brigham Young grew about 1851. Borgeson credits the alfalfa with extra long and strong roots. Its yield and disease resistance are unknown.

Caliverde (F. C. 24900) is a variety developed at the University of California from California Common and a wilt resistant selection of Turkistan alfalfa. It lacks winter hardiness and therefore is adapted only to the southern part of the United States. It is reported to be resistant to leaf spots, mildew, and bacterial wilt, and gives a high yield in California.

DuPuits (F. C. 24648) is an intermediate variety developed by patent breeders in France and distributed in this country by Northrup-King and Company. It is adapted to northern Europe and reports indicate good yields in a few eastern states. This variety is coarse stemmed, winter hardy, and susceptible to wilt.

Grimm (F. C. 24438) is a variety from Germany which was introduced into Carver County, Minnesota, in 1857 by Wendelin Grimm. It is recommended for northern areas where winter killing is a serious factor. This variety has a diversity of forms, with varied flower color. It is winter hardy but extremely susceptible to bacterial wilt.

Ladak (F. C. 23905) was obtained from India in 1910 by the U. S. D. A. It is adapted to northern areas but not recommended in the southern United States or along the eastern seaboard. This variety is extremely winter hardy, with slow recovery after cutting. It is relatively free from leaf diseases, and shows some resistance to bacterial wilt and dry conditions. Its outstanding characteristic is its ability to produce a large first crop.

Lahontan is a synthetic variety developed from Nemestan sources by O. F. Smith, a U. S. D. A., A. R. S. plant breeder, at the Nevada

Agricultural Experiment Station. It was released in June 1954. It is adapted to the Pacific Coast and Intermountain areas. This variety is upright growing and blooms 6 days earlier than Ranger. It is almost immune to the stem nematode (Ditylenchus dipsaci) and is more resistant to bacterial wilt than Ranger. It is high yielding and highly resistant to the spotted alfalfa aphid.

Narragansett (F. C. 24333) is a synthetic variety developed at the Rhode Island Experiment Station. It has a wide base including Grimm, Canadian Variegated, Hardigan, Cossak, Ladak, and several Medicago falcata strains. It is adapted to the northeast section of the United States. It has a spreading to upright growth, with a much branched root system. It is resistant to leaf spots and foliar diseases, and more tolerant of wilt than Grimm.

Nemestan is an original introduction by H. L. Westover from the Askhabad district of Turkistan. It was tested in Utah and Nevada as F. C. No. 19304 prior to release as a variety. It is recommended only in certain areas of the western states. This variety has resistance to stem nematode and bacterial wilt, but is extremely susceptible to leaf spots. It is characterized by low seed production, fairly low yield and resistance to drought and cold.

Nomad (F. C. 24033) was developed by E. F. Burlingham and Sons in Oregon. It is a selection from alfalfa plants in Klamath County which are adapted to nonirrigated range conditions. This variety has a rather prostrate growth, and a tendency to produce large crowns. It is winter hardy and resistant to rodents.

Ranger (F. C. 24802) is a synthetic variety produced by the Nebraska Agricultural Experiment Station and the U. S. D. A. from selections of Cossack, Turkistan, and Ladak. It is adapted to the northern part of the United States. This variety is the most widely recommended variety in the state of Utah. It is resistant to cold and bacterial wilt, but is susceptible to leaf spot diseases and stem nematode.

Stafford is a selection made by an individual farmer in Nebraska. It is adapted to the central region of the United States. This variety is more susceptible to wilt and less winter hardy than Ranger.

Talent (F. C. 24702) was originally introduced from France in 1935. Fifteen hundred plants were selected at the Oregon Experiment Station to provide the original varietal seed. It is adapted to Oregon and northern California. Talent has resistance to stem nematode and crown wart, but lacks resistance to wilt. It is not too winter hardy and begins growth earlier in the spring than other varieties in Oregon.

Vernal (F. C. 24790) is a synthetic variety made up of crosses of Cossack, _Medicago media_, and _M. falcata_. It was developed at the Wisconsin Agricultural Experiment Station in 1948 and released in 1953. It is adapted to the northern and western parts of the United States. This variety is more resistant to wilt, yellow leaf blotch, and cold temperatures than Ranger.

919 (Nevada) N. K. is distributed by Northrup-King and Company. It was derived from the blending of several varieties. It is reported that some resistance to wilt is bred into it. The seed company claims it is a high yielding variety if used in the area of adaption.

METHODS AND PROCEDURE

General information concerning the experimental area

The field experiment was located in the north east corner of section 12, township 43 south, and range 16 west on a farm owned by Mr. Clair Sturzenegger. This area is commonly called the "Price Bench" and is situated a few miles south of St. George, Washington County, Utah.

The soil of the area was surveyed in 1936 and classified as Redfield loam. It has a light reddish brown or pale red color, with a mellow texture and very little if any difference between the surface and the subsoil. It contains some lime and gypsum as indicated by the white flecks and faint mottlings in the profile, and normally has a few traces of soluble salt.

The temperature of the Washington County area is relatively high compared to other farming areas of the state. The high, low, and average temperatures for the growing season during the years 1955 and 1956 are listed in table 1.

This is an area of low rainfall and irrigation must be practiced for successful crop production. The precipitation and the departure from normal during the growing seasons of March through September for both years are shown in table 2.

Field experimental plots

Seventeen varieties of alfalfa were planted in a random block design of 4 replications on the Sutrzenegger farm, March 11, 1956, by D. R. McAllister, M. W. Pedersen, and J. K. Hughes. This planting was one of a series to be made throughout the state of Utah to study the

Table 1. High, low, and average temperatures (March through September) at St. George, Utah, for 1955 and 1956 (Fahrenheit readings)*

Month	1955			1956		
	High	Low	Average	High	Low	Average
March	78	22	50	89	22	53
April	82	31	58	88	33	61
May	97	37	68	100	40	71
June	107	39	76	**	**	**
July	110	53	82	109	58	85
August	**	**	**	104	58	83
September	104	38	73	**	**	**

* From Climatological Data for Utah (1955 and 1956)
** Not reported

Table 2. Monthly precipitation in inches at St. George, Utah, (March through September) for 1955 and 1956*

Month	1955		1956	
	Precipitation	Departure from Normal	Precipitation	Departure from Normal
March	.14	-.69	.00	-.83
April	.06	-.44	.18	-.32
May	.00	-.40	.52	+.12
June	.06	-.10	**	**
July	1.61	+.90	1.26	+.55
August	2.53	+.79	.08	-.67
September	.18	-.45	**	**

* From Climatological Data for Utah (1955 and 1956)
** Not reported

response of alfalfa varieties to different environments.

The individual plots of alfalfa were 8 feet by 50 feet, and consisted of 10 rows, 2 planted on each of 5 beds. No alleyways were made between the plots or at the ends of plots. There were 9 rows of 919 (Nevada) N. K. planted on the east and 1 row of an unknown variety planted on the west as a border.

The plants were examined for height and stand on August 8, 1954. All of the varieties had good stands and fair height with the exception of Nomad. The ratings for the individual varieties are given in table 3.

Treble superphosphate fertilizer was broadcast August 16, 1954, through a Gandy spreader hole No. 11, on the lower half of all replications, at the rate of 161 pounds of P_2O_5 per acre.

Counts of plants infected with fusarium

A general observation of the experimental area indicated that there were varietal differences in the number of plants showing the typical straw colored foliar symptoms of fusarium wilt.

The 2 central rows of each plot were selected to sample the extent of infection. A visual count was made of the actual number of plants showing the fusarium symptoms, and separate totals were maintained for the fertilized and non-fertilized sections of each plot. These counts were made just prior to the harvest of second crop for the 2 seasons, 1955 and 1956. Infected plants were most obvious at this time and upright plant growth habit permitted an accurate count.

The data were statistically analyzed to determine if a significant difference existed between the varieties in the number of plants infected with fusarium.

Table 3. Ratings of varietal stands of 17 varieties of alfalfa planted March 11, 1954, and rated August 8, 1954

Variety	Height in inches	Stand* (Estimated)
Arizona Chilean	14	10
Atlantic	13	10
Buffalo	13	8
B. Y. Strain	11	10
Caliverde	14	9
DuPuits	13	8
Grimm	12	8
Ladak	9	8
Lahontan	15	9
Narragansett	11	9
Nemestan	13	8
Nomad	5	6
Ranger	11	8
Stafford	12	9
Talent	11	7
Vernal	10	8
919 (Nevada) N. K.	15	9

* Stand rating 1-10 with 10 being best and indicating a normal number of plants per plot.

Nematode study

Ten samples of soil from the 0" to 4" region were collected at random from the experimental plot area on August 8, 1955. Each sample was placed in a polyethylene bag, labeled, and tied with an elastic band. They were taken to the regional nematode laboratory in Salt Lake City and examined for the presence of nematodes.

In the early spring of 1956 the experimental plots were again sampled for a nematode study. Each variety sample consisted of 4 to 5 plants from the outside row of the second replication. These plants which showed typical nematode symptoms were dug with a shovel and placed in No. 10 Kraft bags. They were taken to Salt Lake City where Gerald Thorne and Ed. Jorgenson, U. S. D. A. nematologists, examined them for the presence of stem nematodes.

Root study

An investigation was made during the summer of 1956 to determine the extent of root rot in a representative sample of plants from each variety. Replication 1 was sampled after the harvest of the first crop in May and replications 2, 3, and 4 were sampled after the harvest of the second crop in July.

The selected sample area consisted of a 2 foot length of the 6 central rows of each plot and was located 2 feet from the bottom of each replication. All the plants in the sample area were dug with a shovel and laid on a 4 foot by 4 foot weighing canvas. (See figure 1.) Roots were cut diagonally at intervals and rated as to the extent of cortical and vascular discoloration. Plants were rated with reference to fusarium as follows: (1) Number of healthy plants, (2) Number of lightly infected plants, (3) Number of moderately infected plants, (4) Number of heavily infected plants, and (5) Number of dead plants.

Figure 1. Method of sampling St. George experimental plots for the determination of alfalfa root rot, July 1, 1956

The roots which showed disease symptoms other than fusarium were also noted. The results were analyzed statistically.

Soil samples

A total of 32 soil samples were taken from the experimental plot area on September 11, 1956. Four samples were taken from the fertilized portion of each replication and 4 from the unfertilized portion. On the same date 10 random soil samples were taken from a *Phymatotrichum* infected area 250 feet west of the experimental plots.

All samples were taken with a 3 inch soil auger from the 0" to 12" depth, placed in polyethylene bags, and taken to the U. S. D. A. Soils Laboratory at Utah State Agricultural College. These samples were analyzed for pH, phosphorus, and total soluble salt by James P. Thorne, soil scientist.

Culture of organisms

Random samples of diseased plants were dug following the cutting of fourth crop hay in 1956. They were placed in an ice cream packer and brought to the college. Stems, crown buds, and branch roots were removed and discarded. The tap roots were washed and placed in a bucket under a force of running water for 24 hours to remove surface organisms. They were then rinsed in sterile distilled water. The roots were then taken into the pathology laboratory transfer room which had previously been disinfected with mercuric chloride solution and ultraviolet light. They were peeled back and 4 small cuttings taken from the cortex and vascular regions of each of 37 tap roots. The scalpels used were disinfected between cuttings by dipping in 70 percent ethyl alcohol and flaming. The 4 root pieces were placed in a quadrant manner in sterile petri dishes containing 2 percent bactoager and were allowed to incubate for 12 days at room temperature.

Taproot samples 1-15 were taken from yellow to reddish brown discolored areas of the cortex and vascular tissues. Samples 16-23 were taken from reddish brown to black discolored cortex and vascular tissues just above an area where the root had been completely rotted off. Samples 24-29 were taken from reddish brown to black streaks of discoloration in the vascular tissues. Samples 30-37 were taken from margins of dark brown lesions in the cortex.

On September 24, 1956, a few hyphae from each of the different appearing mycelial growths from each quadrant culture were transferred, under sterile conditions, to a sterile petri dish containing potato dextrose agar (Ricker and Ricker 1936).

The potato dextrose agar plates were placed in an incubation cabinet and held at room temperature for 30 days. A microscopic study was then made in an effort to identify the fungi.

Yield

Four crops were harvested from the plot areas during the summer of 1955 and again during the summer of 1956.

In 1955 a stake was placed every 25 feet along 2 sides of the experimental area to note the point of division of subplots. A tight string was held between 2 stakes on the subplot lines and a strip 30 inches wide was cut across the area with a Jari power scythe. The hay was removed from these strips and placed in piles outside the experimental area to avoid interference with further cutting. The 2 outside rows of each individual subplot were cut and discarded to avoid border effects and the central 6 rows of the subplot were cut for yield.

A Farmall Cub tractor was used to cut the hay. It was gathered with pitch forks, placed on 4 x 4 canvases and immediately weighed.

During the year 1956 the harvests were made in a similar manner to that recorded above for 1955, with 1 exception; the subplots were separated by straddling the string and trampling down a strip of hay across the subplot lines rather than cutting with the power scythe.

The percent moisture in the green hay was estimated for each crop. It varied between 25 and 30 percent based upon the precipitation and stage of growth prevalent at the time of harvest.

The yields of the first and fourth crops for both years were adjusted to remove grass and weeds. In first crop in 1955 it was estimated that Nemestan, Lahontan, and Arizona Chilean varieties had an average of 10 percent Melilotus indica in each plot. Nomad had 52 percent in each plot and other varieties ranged from 17 to 37 percent. The fourth crop of 1955 and the first and fourth crops of 1956 were infested with Seteria lutescens, S. viridis, Plantago lanceolata, Rume crispus, Sonchus arvensis, and Lolium spp. Estimated percentages for the varietal plots were similar for the 3 crops. Lahontan, Nemestan, Caliverde, and Arizona Chilean averaged 5 percent or less. The variety Nomad had a range of 57 to 64 percent in the 3 crops and other varieties ranged between 10 and 47 percent weeds and grass.

The data for the 2 years were statistically analyzed on a dry weight, weed free basis to determine whether a significant yield difference existed.

RESULTS

The results presented here are arranged in the same order as in the methods of procedure.

Fusarium counts

The means for the number of plants infected with fusarium wilt are listed in table 4. The analysis of variance shows a significant difference at the 1 percent level for the year 1955, and at the 5 percent level for 1956.

Fusarium count means for 1955 are listed in ranked order in table 5, and Duncan's (1955) Multiple Range test was used to test the significant difference between the varieties. This test is based on the factor that the difference for significance between means varies with the number of means in the comparison. The difference required for significance increases as means further apart in rank are compared. There is no significant difference between any 2 means which are found in the same range. A significant difference does exist between those means which are not found within the least significant range.

The variety Lahontan had the smallest mean number of infected plants during 1955, however, it was not significantly different from Nemestan, Talent, DuPuits, Nomad, Vernal, or Narragansett. The variety 919 (Nevada) N. K. had a significantly higher mean number of infected plants than any other variety. Other comparisons can be made by referring to the table.

Variety means of fusarium counts for 1956 are listed in table 6. Using a Duncan's Multiple Range test at the 5 percent level, a series

Table 4. Means of fusarium infected plants during the second cutting of 2 crop years

Variety	1955	1956	Total
Arizona Chilean	18.7	5.7	24.4
Atlantic	17.0	10.2	27.2
Buffalo	25.7	6.0	31.6
B. Y. Strain	19.7	5.7	25.4
Caliverde	22.0	7.2	29.2
DuPuits	13.2	8.2	21.4
Grimm	24.5	9.0	33.5
Ladak	17.5	7.5	25.0
Lahontan	2.7	1.5	4.2
Narragansett	16.5	11.7	28.2
Nemestan	5.0	3.0	8.0
Nomad	13.7	6.7	20.4
Ranger	19.2	7.5	26.7
Stafford	18.2	7.5	25.7
Talent	10.0	8.2	18.2
Vernal	15.2	6.2	21.4
919 (Nevada) N. K.	41.5	13.0	54.5
$\bar{X}$	17.6	7.3	12.5
F values for Varieties	71.22**	2.46*	10.03**
F value - Variety x Years			100.40**
S $\bar{x}$	3.25	1.48	3.38
C. V. percent	36.8	49.0	54.1

* Significant at .05 level
** Significant at .01 level

Table 5. Ranked varietal means of fusarium infected plants for the year 1955

Variety	Means	* Least significant ranges at the 1 percent level (Duncan's Multiple Range test)
Lahontan	2.75	
Nemestan	5.00	
Talent	10.00	
DuPuits	13.25	
Nomad	13.75	
Vernal	15.25	
Narragansett	16.50	
Atlantic	17.00	
Ladak	17.50	
Stafford	18.25	
Arizona Chilean	18.75	
Ranger	19.25	
B. Y. Strain	19.75	
Caliverde	22.00	
Grimm	24.50	
Buffalo	25.75	
919 (Nevada) N. K.	41.50	

* A significant difference exists between any 2 means which are not found within the same range. There is no significant difference between any 2 means within the same range.

Table 6. Ranked varietal means of fusarium infected plants for the year 1956

Variety	Means	* Least significant ranges at the 5 percent level (Duncan's Multiple Range test)
Lahontan	1.50	
Nemestan	3.00	
Arizona Chilean	5.75	
B. Y. Strain	5.75	
Buffalo	6.00	
Vernal	6.25	
Nomad	6.75	
Caliverde	7.25	
Ranger	7.50	
Stafford	7.50	
Ladak	7.50	
Talent	8.25	
DuPuits	8.25	
Grimm	9.00	
Atlantic	10.25	
Narragansett	11.75	
919 (Nevada) N. K.	13.00	

* A significant difference exists between any 2 means which are not found within the same range. There is no significant difference between any 2 means within the same range.

of least significant ranges were established. Lahontan again had the least mean number of infected plants. It was not significantly different from Vernal or the other 4 varieties in the interval between, but did show significance when compared with the other 11 varieties being studied. The variety 919 (Nevada) N. K. has the highest infection, but does not show significance when compared with 5 of the other varieties being tested.

The ranked means of fusarium infected plants for the 2 years combined are listed in table 7. At the 1 percent level Lahontan had the least mean number of diseased plants and was significantly different from all other varieties with the exception of Nemestan. This was probably due to the difference between varietal infections in one year and the next. While the varieties, Lahontan and Nemestan remained in the same rank, Talent dropped from third in 1955 to twelfth in 1956. DuPuits changed from fourth to thirteenth, Arizona Chilean, which ranked eleventh in 1955, became third in 1956. These varieties serve only as examples, since several other comparisons of change in variety rank could be cited from observations of tables 5 and 6.

The variety 919 (Nevada) N. K. was the most seriously infected variety during the 2 years and the multiple range test indicates that there is significance between it and all other varieties tested.

Nematode study

Gerald Thorne, U. S. D. A. nematologist, examined the soil samples taken from the experimental plots in August 1955. He reported that the stem nematode (*Ditylenchus dipsaci*) was not present. Eleven other nematode species were identified, but they were not pathogenic on alfalfa.

Table 7. Ranked varietal means of fusarium infected plants for the years 1955 and 1956 combined

Variety	Means	* Least significant ranges at the 1 percent level (Duncan's Multiple Range test)
Lahontan	4.25	
Nemestan	8.00	
Talent	18.25	
Nomad	20.50	
Vernal	21.50	
DuPuits	21.50	
Arizona Chilean	24.50	
Ladak	25.00	
B. Y. Strain	25.50	
Stafford	25.75	
Ranger	26.75	
Atlantic	27.25	
Narragansett	28.25	
Caliverde	29.25	
Buffalo	31.75	
Grimm	33.50	
919 (Nevada) N. K.	54.50	

* A significant difference exists between any 2 means which are not found within the same range. There is no significant difference between any 2 means within the same range.

In the early spring of 1956 it was very evident that nematodes were having an effect on the growth of the alfalfa plants. Varieties known to have resistance to nematodes, namely, Lahontan, Nemestan, and Talent were 3 to 4 inches high, and the majority of plants exhibited a healthy condition. All other varieties exhibited extremely poor growth apparently due to the action of the nematodes. (See figure 2.)

An estimate of the percent of plants infested with nematodes indicated that resistance was a big factor in the maintenance of stands. The varieties, Nemestan, Lahontan, and Talent had 5, 7.2, and 13.5 percent infected plants, respectively; while Nomad was 88.5 percent infected, and Narragansett was 85.5 percent infected. The other varieties averaged between 50 and 60 percent infection.

Samples of plants from the second replication of the experimental plot area at St. George, and other miscellaneous samples from Hurricane, Kanab, and the Washington fields, were analyzed by Gerald Thorne at Salt Lake City in March of 1956. Stem nematodes were found in all samples except those from Kanab. One root which had the typical symptoms of root knot nematode (Meloidgne spp.) was found in the variety Lahontan. (See figure 3.)

During the cutting of first crop hay in May 1956, the effects of the nematodes were still evident in the foliage. Infected stems were enlarged for about 6 inches from the basal end to a point where the plant began to show normal growth. The infected stems were discolored, hard, and brittle.

Root infections

The number of diseased plants, healthy plants, and the percent healthy plants as determined by the examination of diagonal cut surfaces of the roots extracted from a 2 foot by 5 foot sample area at

Figure 2. Stem nematode resistance as exhibited by Lahontan alfalfa on the left and Nemestan alfalfa on the upper right. Susceptibility is exhibited by Buffalo alfalfa on the lower right. D. R. McAllister (left) holds a damaged crown, while J. C. Theurer holds a healthy crown. St. George, Utah, March 23, 1956.

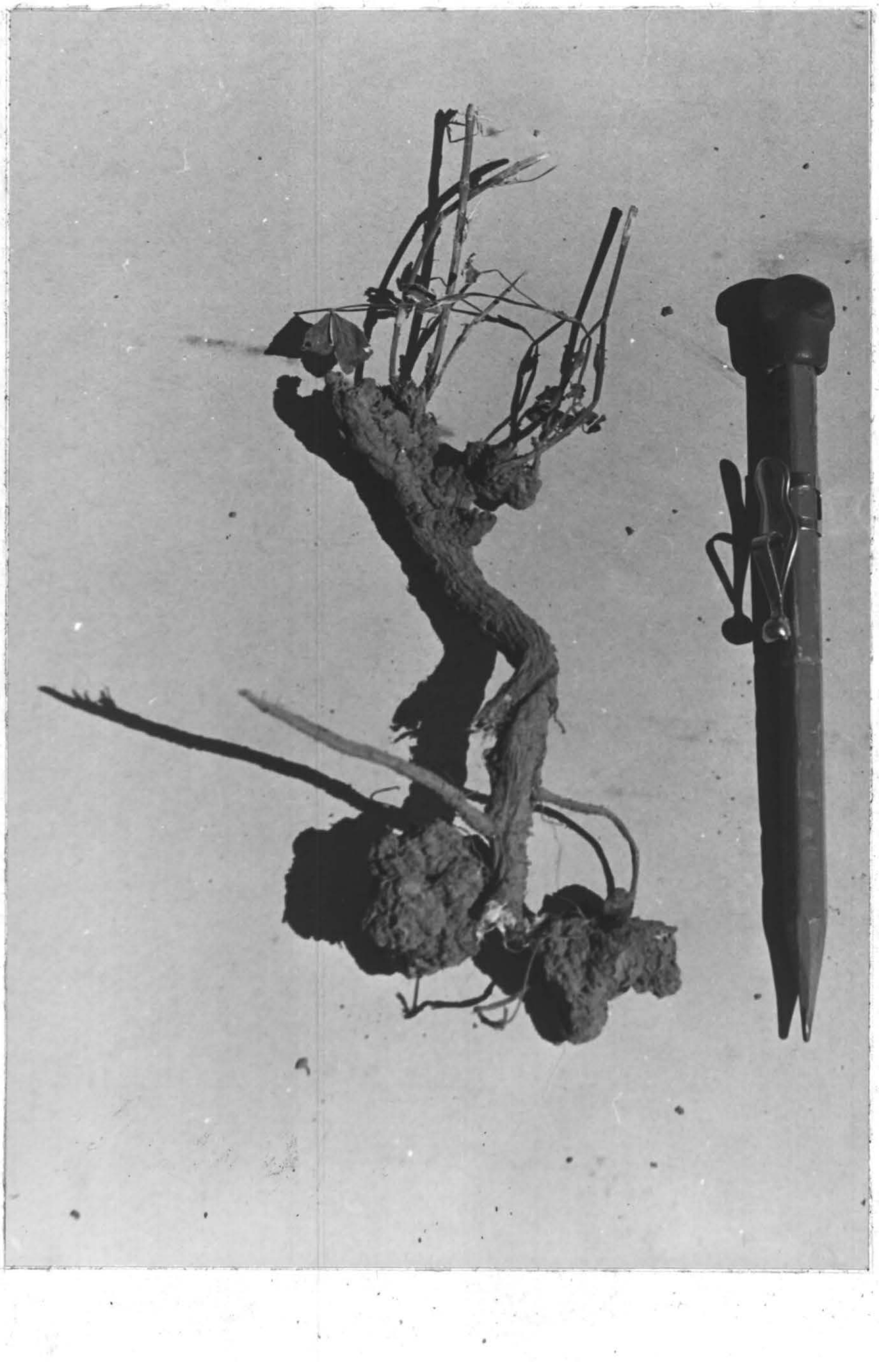

Figure 3. Alfalfa root infested with root knot nematode (Meloidgne spp.) from St. George plots, July 2, 1956

St. George are shown in table 8. Nemestan, Lahontan, and Arizona Chilean varieties produced the greatest number of plants. The size, condition, and number of roots in each variety, from samples of the second replication of the experimental plots, are pictured in figures 4, 5, 6, and 7. Sixty-five percent of the roots from the samples of Lahontan and Nemestan were healthy. All other varieties exhibited more diseased than healthy plants. A statistical test of the independence between varieties gave a Chi-square value of 273.247, which is more than 8 times the value required for significance at the 1 percent level.

Weighted means and a multiple range test for the extent of fusarium infection are given in table 9. The number of plants extracted in a sample was not equal for all varieties, therefore, the original numbers were changed to percent for comparison. The percent of healthy plants was not changed. The percent of lightly infected plants was multiplied by 2. Classifications 3 (moderate infections), 4 (heavy infections), and 5 (dead plants) were multiplied by 3, 4, and 5, respectively for each variety. This weighting factor enables one to observe the differences in the severity of infection. The variety Lahontan, for example, has the lowest mean because of the abundance of healthy and lightly infected plants and the small number of heavily infected or dead plants. No significant difference exists however, between Lahontan and Ranger, or the other 6 varieties in the interval between them at the 1 percent level.

<u>Analysis of soil samples</u>

An analysis of soil samples from the St. George experimental area for pH, phosphate, and total soluble salt is listed in table 10. Sample numbers without a letter prefix are from the experimental plots.

Table 8. Ratio of diseased-healthy plants of each variety as determined by examination of the diagonal cut surfaces of plant roots

Variety	Number of Diseased Plants	Number of Healthy Plants	Percent Healthy Plants
Lahontan	87	193	68.9
Nemestan	96	196	67.1
Talent	94	85	47.5
Nomad	61	55	47.4
Vernal	102	78	43.4
Caliverde	118	67	41.6
Arizona Chilean	171	109	38.9
Ranger	103	57	35.6
Ladak	61	30	32.9
B. Y. Strain	126	60	32.2
Buffalo	104	49	32.0
Stafford	97	45	31.7
DuPuits	49	20	29.0
Grimm	107	37	25.7
Atlantic	91	30	25.6
Narragansett	83	25	23.1
919 (Nevada) N. K.	111	26	19.0
Total	1661	1162	

$X^2 = 273.247$

Figure 4. Alfalfa roots of the varieties Narragansett, Talent, Lahontan, and Atlantic from replication 2 of the St. George plots, July 1, 1956

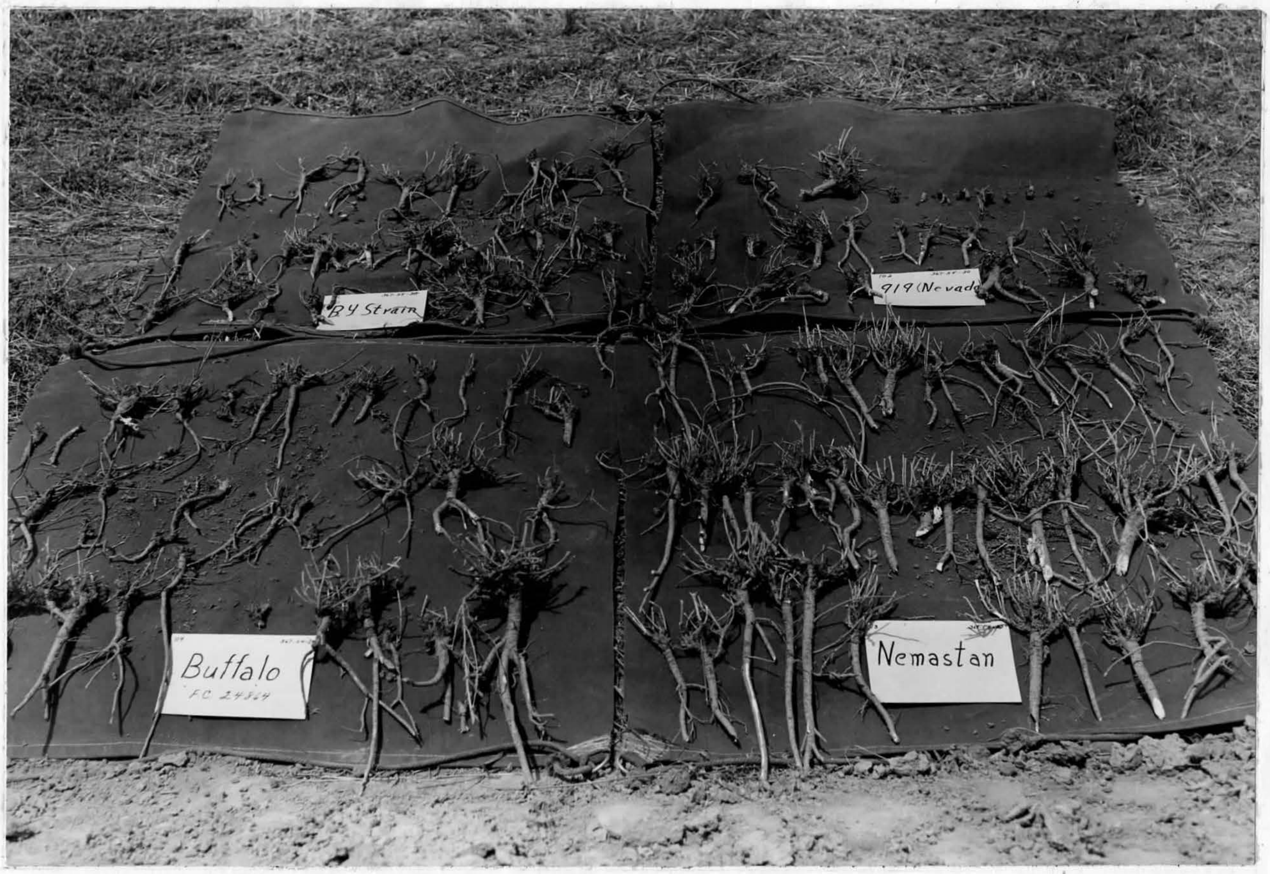

Figure 5. Alfalfa roots of the varieties B. Y. Strain, 919 (Nevada) N. K., Buffalo, and Nemestan from replication 2 of the St. George plots, July 1, 1956

Figure 6. Alfalfa roots of the varieties Arizona Chilean, Stafford, Ranger, and Caliverde from replication 2 of the St. George plots, July 1, 1956

Figure 7. Alfalfa roots of the varieties Grimm, Ladak, Nomad, DuPuits, and Vernal from replication 2 of the St. George plots, July 1, 1956 .

Table 9. Variety means for the extent of fusarium infection determined by examination of plant roots

Variety	Variety Means (Weighted values)[2]	* Least significant ranges at the 1 percent level (Duncan's Multiple Range test)
Lahontan	143.75	
Nemestan	156.00	
Talent	162.25	
Nomad	201.25	
Arizona Chilean	226.75	
Vernal	234.75	
Caliverde	237.75	
Ranger	247.75	
B. Y. Strain	265.75	
Ladak	266.00	
Buffalo	272.50	
Stafford	274.75	
DuPuits	292.50	
Atlantic	311.25	
Narragansett	314.25	
Grimm	317.75	
919 (Nevada) N. K.	328.00	
$\bar{X}$	250.18	
F value for Varieties	4.46**	
$S \bar{X}$	25.4	
C. V. percent	20.31	

2. Consists of the arithmetic means of: The percentage healthy plants, 2 times percentage lightly infected plants, 3 times the percentage of moderately infected plants, 4 times the percentage of heavily infected plants, and 5 times the percentage of dead plants taken from a 2' x 5' area within each varietal plot.

** Significant at the .01 level

Table 10. Analyses of St. George soil samples (0" to 12" depth) for pH, phosphorus, and total soluble salt.

Lab. No.	Sample No.	Location	Rep.	pH	Salt Percent	P_2O_5 Lbs./acre
U562646	P-1	Outside plot area		7.3	.31	18
U562647	P-2	" " "		7.3	.24	31
U562648	P-3	" " "		7.6	.30	33
U562649	P-4	" " "		7.5	.26	61
U562650	P-5	" " "		7.7	.17	26
U562651	P-6	" " "		7.7	.10	41
U562652	P-7	" " "		7.9	.11	29
U562653	P-8	" " "		7.8	.28	56
U562654	P-9	" " "		7.9	.23	32
U562655	P-10	" " "		7.7	.12	26
U562656	1	Unfertilized area	I	7.7	.29	20
U562657	2	" "	I	7.6	.23	40
U562658	3	" "	I	7.6	.25	30
U562659	4	" "	I	7.7	.20	44
U562660	5	Fertilized area	I	7.6	.19	54
U562661	6	" "	I	7.6	.27	60
U562662	7	" "	I	7.6	.27	32
U562663	8	" "	I	7.6	.27	28
U562664	9	Unfertilized area	II	7.6	.34	20
U562665	10	" "	II	7.6	.34	44
U562666	11	" "	II	7.7	.32	54
U562667	12	" "	II	7.8	.23	60
U562668	13	Fertilized area	II	7.7	.18	32
U562669	14	" "	II	7.7	.19	28
U562670	15	" "	II	7.7	.30	20
U562671	16	" "	II	7.8	.34	44
U562672	17	Unfertilized area	III	7.6	.30	57
U562673	18	" "	III	7.6	.36	33
U562674	19	" "	III	7.9	.26	59
U562675	20	" "	III	7.9	.24	104
U562676	21	Fertilized area	III	7.8	.24	75
U562677	22	" "	III	7.7	.26	28
U562678	23	" "	III	7.8	.28	51
U562679	24	" "	III	7.8	.39	101
U562680	25	Unfertilized area	IV	7.8	.30	43
U562681	26	" "	IV	7.7	.35	80
U562682	27	" "	IV	7.8	.22	51
U562683	28	" "	IV	7.9	.25	59
U562684	29	Fertilized area	IV	7.9	.28	72
U562685	30	" "	IV	7.9	.20	49
U562686	31	" "	IV	7.8	.30	75
U562687	32	" "	IV	7.9	.30	59

Those with the letter "P" as a prefix are from the Phymatotrichum infected area 250 feet west of the experimental plots. A photograph of this area is presented in figure 8.

Results of the analysis indicate the soil has a pH range from 7.3 to 7.9. The total salt percentage ranged from .10 to .39 percent. The P_2O_5 was extremely variable, indicating that there was an abundance of phosphate in the soil in the unfertilized area as well as in that area which received additional fertilizer.

Culture of the organism

The scientific names of fungi which were isolated from root samples are listed in table 11. It is noted that well over 50 percent were identified as *Fusarium solani*. The culture plates revealed that a great amount of variation existed in this species. (See figure 9.) Two cultures were identified as *Fusarium roseum* (see figure 10), 2 as *Oidium* spp., and 16 of the 48 total incubations could not be identified. The unknown fungi apparently consisted of 6 species. (See figure 11.) The *Fusarium* species were identified by Dr. William C. Snyder, Plant Pathologist at the University of California.[1]

Results of forage yield determinations

Variety forage yield means for 1955 and 1956 are listed in table 12. F tests indicate that the varietal differences were highly significant for each individual crop and for the analysis of all crops combined. Varieties x crops were also significant to the 1 percent level.

1. Dr. Snyder stated in a personal letter to the author dated October 30, 1956, that *Fusarium solani* and *F. oxysporum* often appear as one fungus when grown in co-culture, and that it would be quite possible that *F. oxysporum* is present in some of the cultures since isolations were from mycelial strands and not from single spores.

Figure 8. Phymatotrichum root rot rings in the Clair Sturzenegger alfalfa field at St. George, Utah, August 1955

Table 11. Fungi isolated in 1956 from diseased alfalfa roots

Sample No.	Fungus isolated	Sample No.	Fungus isolated
1	Unidentified	20B	F. solani
2	Fusarium solani	21	F. solani
3	Unidentified	22	Unidentified
4	Unidentified	23	Unidentified
5	F. solani	24A	Unidentified
6	Unidentified	24B	F. solani
7	Unidentified	25	Unidentified
8	F. solani	26	Unidentified
9	Unidentified	27	Unidentified
10	Unidentified	28	F. solani
11	Unidentified	29	F. solani
12	Oidium spp.	30	F. solani
13	Oidium spp.	31	Unidentified
14	F. solani	32A	F. roseum
15A	F. solani	32B	Unidentified
15B	F. solani	32C	F. solani
16	F. solani	33	F. solani
17A	F. solani	34A	F. solani
17B	F. solani	34B	F. solani
18A	F. solani	35A	F. solani
18B	F. solani	35B	F. solani
19A	F. solani	36A	F. solani
19B	F. solani	36B	F. solani
20A	F. solani	37	F. roseum

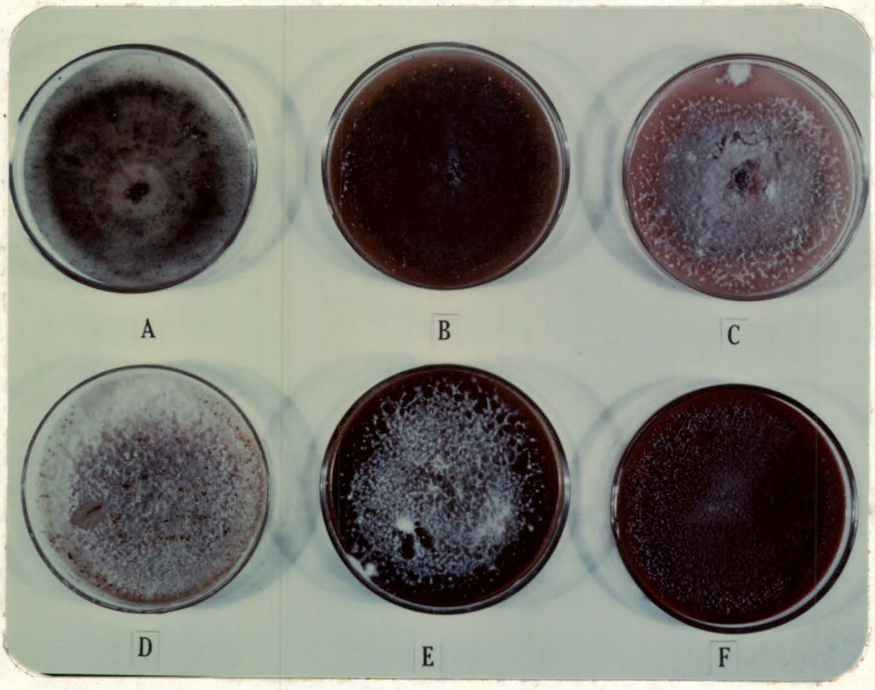

Figure 9. Culture variations of Fusarium solani isolated from infected alfalfa roots taken from the St. George plots in October 1956

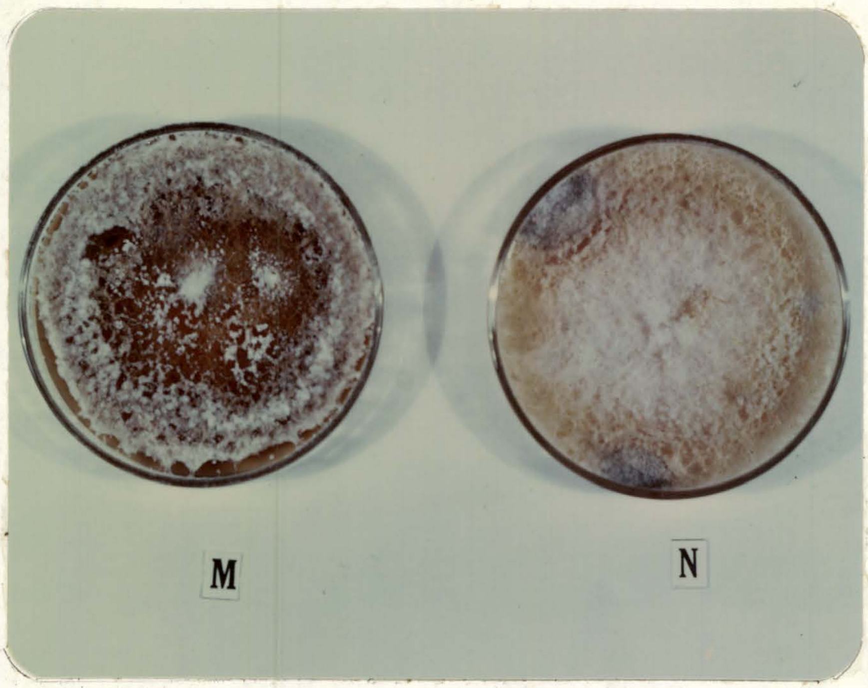

Figure 10. Culture variations of Fusarium roseum isolated from infected alfalfa roots taken from the St. George plots in October 1956

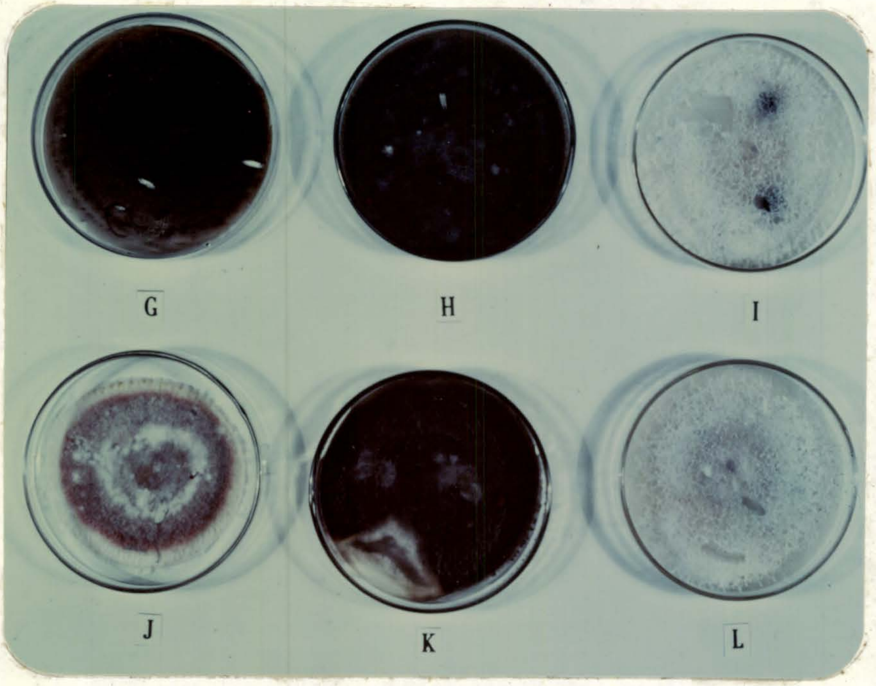

Figure 11. Unidentified cultures of fungi isolated from infected alfalfa roots taken from the St. George plots in October 1956

Table 12. Crop means for years 1955 and 1956 combined

Variety	1st Crop Tons/acre	2nd Crop Tons/acre	3rd Crop Tons/acre	4th Crop Tons/acre	Total Tons/acre
Arizona Chilean	5.15	3.10	2.40	2.10	12.75
Atlantic	4.65	2.80	2.05	1.45	10.95
Buffalo	4.35	2.75	2.35	1.95	11.40
B. Y. Strain	4.15	2.75	2.10	1.50	10.50
Caliverde	4.20	3.10	2.40	2.00	11.70
DuPuits	3.95	2.80	1.70	0.95	9.40
Grimm	3.20	2.50	2.10	1.60	9.40
Ladak	2.95	2.20	1.65	1.20	8.00
Lahontan	5.40	3.85	3.20	2.25	14.70
Narragansett	2.30	2.25	1.70	1.10	7.35
Nemestan	5.45	3.80	3.35	2.25	14.85
Nomad	2.35	1.75	1.45	0.60	6.15
Ranger	4.50	3.05	2.65	1.75	11.95
Stafford	4.60	3.00	2.25	1.75	11.60
Talent	4.40	3.50	2.50	1.65	12.05
Vernal	3.70	2.90	2.20	1.50	10.30
919 (Nevada) N. K.	3.45	2.60	2.20	1.85	10.10
$\overline{X}$	4.05	2.65	2.25	1.60	10.75
F values variety	7.95**	14.45**	13.15**	9.55**	11.32**
F values - Variety x Crop					8.01**
S $\overline{x}$	.68	.29	.28	3.0	1.38
C. V. percent	20.9	10.00	12.4	18.4	12.9

** Significant at .01 level

Ranked means of first crop yields for the 2 years and the multiple range test of the means are listed in table 13. Nemestan produced the highest mean yield but did not show significance from 10 other varieties. The variety Narragansett was not significantly different from Nomad, Ladak, Grimm, or 919 (Nevada) N. K. even though it had the smallest mean yield.

A comparative test of ranked means for second crop yields of the 2 years combined is presented in table 14. The variety Lahontan was significantly higher in yield than any of the other varieties listed with the exception of Nemestan and Talent. Nomad was the poorest yielding variety, and showed a significant difference with all varieties except Ladak and Narragansett.

The multiple range test of the ranked means of third crop yields for 1955 and 1956 combined is presented in table 15. The varieties Lahontan and Nemestan show a high degree of significance at the 1 percent level when compared with the other 15 varieties. There was no appreciable difference between Lahontan and Ranger, but a significant difference does exist between Lahontan and all other varieties.

Ranked means for combined fourth crop yields are listed in table 16. The least significant ranges are quite broad and include several varieties. Lahontan has the highest mean average yield, but is not significantly different from 9 other varieties. Nomad, the poorest yielding variety, is significantly different from all varieties except DuPuits, Narragansett, and Ladak.

A review of tables 13, 14, 15, and 16 indicates that Lahontan and Nemestan exhibited the highest mean yields for all 4 crops. The significant difference between these varieties and others is high during the second and third crops, but rather low during the first and fourth

Table 13. Ranked means of first crop yields for years 1955 and 1956 combined

Variety	Means Tons/acre	* Least significant ranges at the 1 percent level (Duncan's Multiple Range test)
Nemestan	5.45	
Lahontan	5.40	
Arizona Chilean	5.15	
Atlantic	4.65	
Stafford	4.60	
Ranger	4.50	
Talent	4.40	
Buffalo	4.35	
Caliverde	4.20	
B. Y. Strain	4.15	
DuPuits	3.95	
Vernal	3.70	
919 (Nevada) N. K.	3.45	
Grimm	3.20	
Ladak	2.95	
Nomad	2.35	
Narragansett	2.30	

* A significant difference exists between any 2 means which are not found within the same range. There is no significant difference between any 2 means within the same range.

Table 14. Ranked means of second crop yields for years 1955 and 1956 combined

Variety	Means Tons/acre	* Least significant ranges at the 1 percent level (Duncan's Multiple Range test)
Lahontan	3.85	
Nemestan	3.80	
Talent	3.50	
Arizona Chilean	3.10	
Caliverde	3.10	
Ranger	3.05	
Stafford	3.00	
Vernal	2.90	
Atlantic	2.80	
DuPuits	2.80	
Buffalo	2.75	
B. Y. Strain	2.75	
919 (Nevada) N. K.	2.60	
Grimm	2.50	
Narragansett	2.25	
Ladak	2.20	
Nomad	1.75	

* A significant difference exists between any 2 means which are not found within the same range. There is no significant difference between any 2 means within the same range.

Table 15. Ranked means of third crop yields for years 1955 and 1956 combined

Variety	Means Tons/acre	* Least significant ranges at the 1 percent level (Duncan's Multiple Range test)
Nemestan	3.35	
Lahontan	3.20	
Ranger	2.65	
Talent	2.50	
Arizona Chilean	2.40	
Caliverde	2.40	
Buffalo	2.35	
Stafford	2.25	
Vernal	2.20	
919 (Nevada) N. K.	2.20	
B. Y. Strain	2.10	
Grimm	2.10	
Atlantic	2.05	
DuPuits	1.70	
Narragansett	1.70	
Ladak	1.65	
Nomad	1.45	

* A significant difference exists between any 2 means which <u>are not</u> found within the same range. There is no significant difference between any 2 means within the same range.

Table 16. Ranked means of fourth crop yields for years 1955 and 1956 combined

Variety	Means Tons/acre	* Least significant ranges at the 1 percent level (Duncan's Multiple Range test)
Lahontan	2.25	
Nemestan	2.25	
Arizona Chilean	2.10	
Caliverde	2.00	
Buffalo	1.95	
919 (Nevada) N. K.	1.85	
Ranger	1.75	
Stafford	1.75	
Talent	1.65	
Grimm	1.60	
Vernal	1.50	
B. Y. Strain	1.50	
Atlantic	1.45	
Ladak	1.20	
Narragansett	1.10	
DuPuits	.95	
Nomad	.60	

* A significant difference exists between any 2 means which <u>are not</u> found within the same range. There is no significant difference between any 2 means within the same range.

crops. Nomad, Narragansett, and Ladak were among the poorest yielding varieties for all 4 crops.

The variety means of yield for the years 1955 and 1956 combined are tabulated in table 17. F values were significant to the 1 percent level for the individual years and for the 2 years combined. A highly significant value was also obtained for the varieties x years interaction.

Ranked means and least significant ranges for a multiple range test of varietal yields during the year 1955 are presented in table 18. Nemestan, with a mean of 16.2 tons per acre, was not significantly different from 919 (Nevada) N. K. and all other varieties in the interval between these varieties. Nomad was the poorest yielding variety but did not show significance when compared with Narragansett and Ladak.

The means for varietal yields during the year 1956 are presented with least significant ranges at the 1 percent level in table 19. Lahontan had a significantly higher yield than any variety other than Nemestan. The yield of Nemestan was also better than any other variety with the exception of Talent. Other least significant ranges are quite broad.

A review of Duncan's Multiple Range test over the 2 years as presented in tables 17 and 18 illustrates the effect that the nematode and disease complex had upon varietal yields. Arizona Chilean ranked second in 1955 but dropped to fourth in 1956, while Talent being resistant to the stem nematode moved from ninth in 1955 to third in 1956. Nemestan and Lahontan retained their mean yield better than all other varieties in this study.

Ranked means and the appropriate multiple ranges for the varietal yields for 1955 and 1956 combined are tabulated in table 20. Nemestan

Table 17. Variety means of yield for the years 1955 and 1956 combined

Variety	1955 Tons/acre	1956 Tons/acre	Total Tons/acre
Arizona Chilean	7.95	4.80	12.75
Atlantic	7.35	3.60	10.95
Buffalo	7.25	4.15	11.40
B. Y. Strain	6.70	3.80	10.50
Caliverde	7.55	4.15	11.70
DuPuits	6.05	3.35	9.40
Grimm	6.15	3.25	9.40
Ladak	5.85	2.15	8.00
Lahontan	7.80	6.90	14.70
Narragansett	5.55	1.80	7.35
Nemestan	8.10	6.75	14.85
Nomad	4.35	1.80	6.15
Ranger	7.80	4.15	11.95
Stafford	7.45	4.15	11.60
Talent	6.95	5.10	12.05
Vernal	6.65	3.65	10.30
919 (Nevada) N. K.	6.50	3.60	10.10
$\bar{X}$	6.80	3.95	10.75
F values for Varieties	6.61**	15.83**	11.32**
F value - Varieties x Years			14.30**
S $\bar{X}$	.78	.72	1.38
C. V. percent	11.3	18.1	12.9

** Significant at .01 level

Table 18. Ranked means of varietal yields for the year 1955

Variety	Means Tons/acre	* Least significant ranges at the 1 percent level (Duncan's Multiple Range test)
Nemestan	8.10	
Arizona Chilean	7.95	
Lahontan	7.80	
Ranger	7.80	
Caliverde	7.55	
Stafford	7.45	
Atlantic	7.35	
Buffalo	7.25	
Talent	6.95	
B. Y. Strain	6.70	
Vernal	6.65	
919 (Nevada) N. K.	6.50	
Grimm	6.15	
DuPuits	6.05	
Ladak	5.85	
Narragansett	5.55	
Nomad	4.35	

* A significant difference exists between any 2 means which are not found within the same range. There is no significant difference between any 2 means within the same range.

Table 19. Ranked means of varietal yields for the year 1956

Variety	Means Tons/acre	* Least significant ranges at the 1 percent level (Duncan's Multiple Range test)
Lahontan	6.90	
Nemestan	6.75	
Talent	5.10	
Arizona Chilean	4.80	
Ranger	4.15	
Caliverde	4.15	
Buffalo	4.15	
Stafford	4.15	
B. Y. Strain	3.80	
Vernal	3.65	
Atlantic	3.60	
919 (Nevada) N. K.	3.60	
DuPuits	3.35	
Grimm	3.25	
Ladak	2.15	
Narragansett	1.80	
Nomad	1.80	

* A significant difference exists between any 2 means which are not found within the same range. There is no significant difference between any 2 means within the same range.

Table 20. Ranked means of varietal yields for years 1955 and 1956 combined

Variety	Means Tons/acre	* Least significant ranges at the 1 percent level (Duncan's Multiple Range test)
Nemestan	14.85	
Lahontan	14.70	
Arizona Chilean	12.75	
Talent	12.05	
Ranger	11.95	
Caliverde	11.70	
Stafford	11.60	
Buffalo	11.40	
Atlantic	10.95	
B. Y. Strain	10.50	
Vernal	10.30	
919 (Nevada) N. K.	10.10	
DuPuits	9.40	
Grimm	9.40	
Ladak	8.00	
Narragansett	7.35	
Nomad	6.15	

* A significant difference exists between any 2 means which <u>are not</u> found within the same range. There is no significant difference between any 2 means within the same range.

had the highest mean but it was not significantly better than Caliverde or the other 4 varieties in the interval between them. Lahontan shows no significant difference when compared with Stafford or any of the varieties above Stafford in the ranked means. The variety Nomad was not significantly different from Narragansett or Ladak, but yielded less than any of the other varieties in this study.

Mean yields for crops for years 1955 and 1956 are listed in table 21. The analysis of variance was calculated and F values indicate a highly significant difference between the crops during the years 1955 and 1956. The F values for crops of both years combined, and F values for years x crop interaction were both significant at the 1 percent level.

A combined analysis of variance for the yields of the 2 years showed a significant F value at the 1 percent level for the fertilizer x year interaction. Fertilizers, and all other interactions with fertilizers, were nonsignificant.

When analyzed separately the 1955 yields of fertilized subplots were significantly different from the nonfertilized subplots. In 1956 no significant difference existed.

Table 21. Means of crop yields for years 1955 and 1956 combined

Crop	1955 Tons/acre	1956 Tons/acre	Total Tons/acre
First crop	2.78	1.26	4.04
Second crop	1.79	1.08	2.87
Third crop	1.30	0.92	2.22
Fourth crop	0.92	0.65	1.57
$\bar{X}$	1.70	0.99	2.69
F values for Crops	228.74**	218.81**	201.99**
F value - Years x Crops			21.01**
S $\bar{x}$	1.77	.59	2.02
C. V. percent	26.1	14.9	18.8

** Significant at .01 level

DISCUSSION

The nematode and disease complex found in Washington County, Utah, is quite similar to those of Nevada (Smith 1948) and Arizona (Keener 1948). This would probably be expected since the climate of these areas is comparable.

The results of this study indicate that stem nematode (*Ditylenchus dipsaci*), *Fusarium* spp., *Phymatotrichum omnivorum*, and *Corynebacterium insidiosum* are the main causal agents of the disease complex which depletes alfalfa stands in 2 to 3 years time. *Phymatotrichum* root rot and bacterial wilt were not found in the experimental plots to any extent, but they were very evident in older stands throughout the county. *Stagnospora meliloti* and *Rhizoctonia solani* and a few unidentified fungi may be minor contributors to the complex.

Stem nematodes were found in every variety during the spring of 1956. Lahontan and Nemestan, and Talent to a lesser degree, showed resistance to the nematodes, which agreed with the findings of Smith (1955) in Nevada and Schoth, *et al*. (1952) in Oregon. These varieties maintained normal growth while all other varieties were stunted, discolored, and deformed. This contrast can be observed in figure 2.

Nematode symptoms were observed in early spring growth in 1956, but were not evident at any other time during the study. Thorne (1932) and Smith (1948) observed that injury was more prominent during the cool, moist spring months, and that the nematodes were inactive during hot dry weather.

The results of this study agree with the report of Steiner (1954) that nematodes are initiators, cooperators, and synergists in disease complexes. There was a direct relationship between the extent of disease infection and the nematode resistance of varieties. Lahontan and Nemestan were the only varieties in the study which had more healthy than diseased roots. Talent with 47.5 percent healthy plants ranked third among the varieties. (See table 8.)

Lahontan, Nemestan, and Talent in respective order were least seriously infected with fusarium, as determined by the examination of cut surfaces of plant roots. The majority of the diseased roots of these varieties had light or moderate discoloration of the cortical and vascular tissue. The roots of all other varieties were more severely infected or dead. Lahontan and Nemestan had crowns which were in good condition with very few dead buds. The crowns of Talent were in fair condition and those of all other varieties were poor. The extreme was found in variety 919 (Nevada) N. K., the crowns of which were severely rotted and only 2 to 3 buds were growing. (See figures 3, 4, 5, and 6.)

A visual count of plants showing foliar symptoms of fusarium wilt during 1955 and 1956 indicated that Lahontan was the least infected variety. Nemestan was second to Lahontan in the least mean number of infected plants. The variety 919 (Nevada) N. K. was by far the most seriously infected variety in this phase of the study. The study and analysis of fusarium disease counts, and examination of the extent of discoloration in diseased roots indicate that Lahontan and Nemestan have some resistance to fusarium wilt.

This could possibly be a genetic characteristic, but probably it is of a mechanical nature, since Weimer (1927) and Staten and

Leyendecker (1949) stated that the fungi usually require an injury to gain entrance into the plant. Results of this experiment indicated that nematodes might provide the main avenues by which fusarium may attack plants. This is similar to the relationship that Smith (1948-1949) found with nematodes and bacterial wilt. In New Mexico 2 breeding strains of alfalfa, NM5-88-0 and NM6-268-0 (Anonymous 1948-1949) and (Anonymous 1949-1950) are reported to be more resistant to fusarium wilt than New Mexico Common. This is the only report that the author is aware of where resistance has been found for fusarium wilt. An experiment to test the resistance of Lahontan and Nemestan in the absence of nematodes would certainly be valuable since very little has been done with this disease since its original discovery in 1926 (Weimer 1926).

As early as 1920, Cottam (1921) recognized fusarium wilt in Utah and Arizona, but did not identify the pathogenic species. In this study *Fusarium solani* was found to be the major pathogen isolated from samples of diseased alfalfa roots. This species was determined to be pathogenic in Arizona by Staten and Leyendecker (1949).

An extensive reinoculation study would be required to determine if any of the other cultures which were isolated are pathogenic on alfalfa.

The varieties Lahontan and Nemestan maintained the best stands during the 2 year period. There were very few weeds and grasses in the plots of these 2 varieties at the end of the fourth crop harvest in 1956. All other varieties had poor stands and were severely infested with weeds, to the point where they were unprofitable to maintain on the land.

Lahontan produced a significantly better yield during 1956 than any of the other varieties except Nemestan. This was due to the resistance which this variety has for nematodes and wilt diseases and its apparent adaptation to the length of season. The results of the yield of this variety are similar to those found in Nevada by Smith (1955).

The variety Lahontan also has resistance to the spotted alfalfa aphid (Therioaphis maculata) which first became prevalent in Washington County in the summer of 1955. The extensive spray program in the county made it difficult to observe the varietal reaction to this insect. The county agent and extension entomologist, however, report that they observed the resistance of Lahontan to this aphid in the experimental area and also in the other fields throughout the county.

Since Phymatotrichum spots were not prevalent in the experimental area, no comparison of varietal resistance to this disease could be observed.

Observation of the data for crop yields during the 2 years indicates that Lahontan shows a greater significant difference between other varieties during the second and third crop than during the first and fourth. This is probably due to the winter hardiness of the variety since it goes into dormancy in the fall earlier than southern varieties and is slower to begin growth in the spring.

The final solution to the problem may possibly be a breeding program to incorporate the resistance of Lahontan into Arizona Chilean, African, or some other better yielding southern strain.

SUMMARY AND CONCLUSIONS

Seventeen varieties of alfalfa were planted in a random block design of 4 replications on the "Price Bench", situated a few miles south of St. George, Utah. This experimental area was used in a study to determine the causal organisms of a disease complex which was raising havoc with the longevity of stands in Washington County, and to compare the forage yields of the 17 varieties.

Stem nematodes (*Ditylenchus dipsaci*) were found in all samples of plants from the experimental plots and from random fields in Hurricane and the Washington fields. Nemestan, Lahontan, and Talent were the only varieties which were not stunted by the action of nematodes during the spring months.

Foliar symptoms of fusarium wilt were evident in all varieties in the experimental area. Lahontan had the least mean number of infected plants, and 919 (Nevada) N. K. was the most severely infected variety. Evidence was found that Lahontan and Nemestan may have resistance to fusarium wilt. Lahontan and Nemestan were the only 2 varieties which had more than 50 percent healthy plants in a sample of roots from a 2 foot by 5 foot area. The crowns of these varieties were well developed and possessed very few dead buds, while those of all other varieties were partially decayed.

Fusarium solani, *F. roseum*, *Oidium* spp., and 6 apparent species of unidentified fungi were isolated from the diseased alfalfa roots from the plot area. Root rot caused by *Phymatotrichum omnivorum* and *Corynebacterium insidiosum* were not found in the plots at St. George, but were prevalent in older fields of alfalfa throughout the county.

Lahontan maintained the highest yield of all varieties studied. In the year 1956 the forage yield of this variety was significantly better than all other varieties except Nemestan. Lahontan was fairly well adapted to the area, but it began growth later in the spring and went into dormancy earlier in the fall than southern varieties.

There was no significant difference observed between the fertilized and unfertilized areas of the experimental plots with respect to the disease complex or to the forage yields.

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